Proposal of a Low cost Mobile Robot Prototype with On-Board Laser Scanner: Robot@Factory Competition Case Study

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Abstract: This paper presents the proposal of a Low cost Mobile Robot prototype with On-Board Laser Scanner, prototyped to compete at the Robot@Factory Mobile Robot competition. The robot is equipped with a hacked Neato XV-11 Laser Scanner, being a very low cost alternative, when compared with the current available laser scanners. It is presented the description of its sensors and actuators, providing valuable information that can be used to develop better designs of controllers and localization systems. The robot is equipped with the 37Dx52L, which is a low cost 12v motor equipped with encoders and a 29:1 reduction gearbox, being a very popular actuator in the mobile robotics domain. The robot is also equipped with an USB camera applied to acquire image, that will be processed, in order to provide information concerning the part material status.

Keywords: Mobile Robots, Prototyping, Sensors, Actuators

1. INTRODUCTION

Nowadays the industry faces the need to have plants more and more flexible. For some tasks, like raw material transportation from one place of work to another, AGVs can be used in order to allow flexible layouts. Theses transporters perform their tasks in a dynamic work environment where unexpected obstacles may appear: the workers can cross the robot path, material left behind can block the intended route and even other robots can be an obstacle (1)(2)(3)(4)(5). Currently, the search for increased efficiency in a plant is a common activity and so AGVs and their deployment becomes a reason of an intense scientific research and pedagogical attention. This topic include fields like: control, localization and navigation. Observing that paradigms, the Robot@Factory competition was designed as a test platform that can be used to solve problems similar to those present in future real plants. The Robot@factory competition attempts to recreate a problem similar to the one that an autonomous robot will face during its use in a plant. This scaled plant has a supply warehouse, a final product warehouse and eight processing machines (6).

The prototyped robot, was projected and prototyped so that it could be low cost and enter the Robot@Factory in a competitive way. The rules limit its size to a 45x40 cm and 35 cm high box. The locomotion system can be built according to different topologies, for example differential, omnidirectional or *Ackerman*. It was adopted an omnidirectional topology with three wheels where there are 120° between each wheel axis. This choice allows independent translation and rotation movements. The four wheel configuration, while having some advantages, requires a mechanical suspension system.

Fig. 1. Robot Prototype

The robot, shown in Figures 1 and 2, is equipped with the 37Dx52L, which is a low cost 12v motor equipped with encoders and a 29:1 reduction gearbox, being a very popular actuator in the mobile robotics domain. The robot is also equipped with a hacked Neato XV-11 Laser Scanner, being a very low cost alternative, when compared with the current available laser scanners. Neato XV-11 is a robot that includes a low cost 360° laser scanner, this sensor can be extracted from the robot, allowing robotics practitioners to use it in their projects.

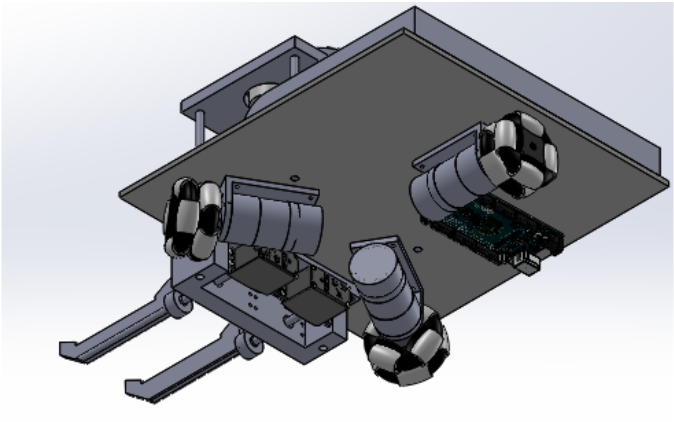

Fig. 2. Robot Prototype CAD

The prototyped robot sensors and actuators are described in the next bsections, finally some conclusions and future work are presented.

2. 37DX52L GEARED MOTOR

The 37Dx52L is an actuator worldwide popular in the mobile robotics domain, being a low cost 12v motor equipped with encoders and a 29:1 reduction gearbox. The fact that it is equipped with encoders is an important feature because it provides important data to obtain the closed loop velocity control and to obtain relative measurements based on the odometry calculation (16). A 37Dx52L is shown in Figure 3.

Fig. 3. 37Dx52L Geared Motor.

The 37Dx52L model can be defined by the following equations, where U_a is the converter output, R_a is the equivalent resistor, L_a is the equivalent inductance and e is the back emf (electromotive force) voltage as expressed by equation (1).

$$U_a = e + R_a I_a + L_a \dot{I_a} \tag{1}$$

The motor can provide a torque T_L that will be applied to the load, being the developed torque (T_d) subtracted by the friction torque, which is the sum of the static friction (T_c) and viscous friction ($B\omega$), as shown in equation 2.

$$T_L = T_d - T_c - B\omega \tag{2}$$

Current I_a can be correlated with the developed torque T_d through equation (3), the back emf voltage can be correlated with angular velocity through equation (4) and the load torque T_L can be correlated with the moment of inertia and the angular acceleration through equation 5 (17).

$$T_d = K_s I_a \tag{3}$$

$$e = K_s \omega \tag{4}$$

$$T_L = J\dot{\omega} \tag{5}$$

In order to obtain experimental data, a setup was implemented. The experimental setup is based on the Arduino micro-controller, the L6207 Drive, a DC Power source and a 37Dx52L actuator. The obtained data is the motor angular velocity and the input voltage. Two tests were performed, the first was to obtain a step response (transitory response data) and the second test was the steady state response for several input voltages (steady state data).

Resorting to equation 2, equation 3 and equation 5, equation 6 was obtained.

$$\dot{\omega} = \frac{K_s I_a - T_c - B\omega}{J} \tag{6}$$

After discretizing equation 6, equation 7 was obtained, where ΔT is the sampling time (50 ms).

$$\omega[k] = \omega[k-1] + \Delta T \frac{K_s i_a[k-1] - T_c - B\omega[k-1]}{J} \tag{7}$$

By minimizing the sum of the absolute error between the estimated (equation 7) and the real transitory response data (assuming initial know values for T_c and K_s), parameters B and J were estimated. Then using equations 1, 2, 3, 4 and 5 and assuming that voltage drop due to L_i is negligible, equation 8 is obtained.

$$J\dot{\omega} = \frac{K_s}{R_a}(U_a - K_s\omega) - B\omega - T_c \tag{8}$$

Solving the first order differential equation, equation 9 is obtained:

$$\omega(t) = \frac{a}{b}(1 - e^{-bt}) \tag{9}$$

where:

$$a = \frac{K_s U_a - R_a T_c}{R_a J} \tag{10}$$

$$b = \frac{K_s^2 + R_a B}{R_a J} \tag{11}$$

In steady state $\omega = \frac{a}{b}$, resulting in equation 12.

$$\omega = \frac{K_s}{K_s^2 + R_a B} U_a - \frac{R_a T_c}{K_s^2 + R_a B} \tag{12}$$

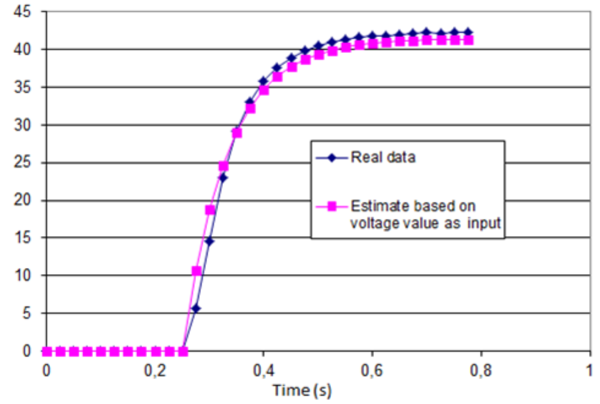

Fig. 4. Motor transitory response data

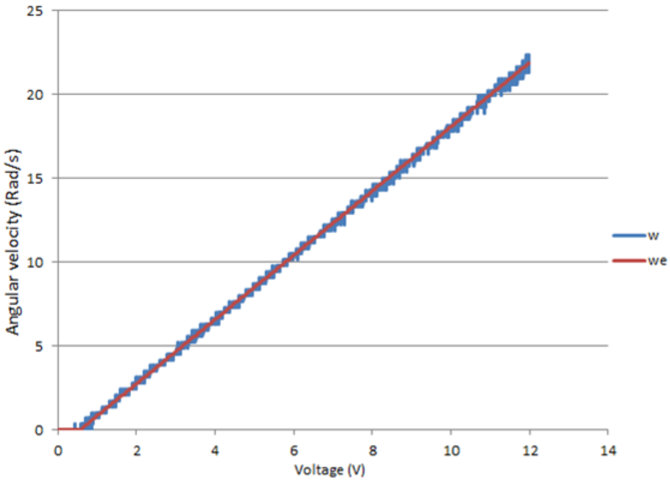

Fig. 5. Motor steady state response data

By minimizing the absolute error between estimated and the steady state data, assuming an initial value for R_a, parameters K_s and T_c are estimated. Finally resorting to equation 9, by minimizing the absolute error between the estimated data and the transitory response data, R_a is estimated. The described optimization process must be repeated until the estimated parameters converge to their true values. Parameters such as T_c, R_a and K_s that are initially assumed as known are replaced by the estimated ones, every time the estimate process is repeated. The estimated and the real transitory and steady state responses are shown in Figures 4 and 5.

The estimated parameters are shown in Table 1, where the presented equivalent inductance was directly measured.

Parameters	Value
K_s	1.89E-4
L_a	3.4E-3
R_a	2.1
B	2.44E-5
T_c	5.95E-5
J	2.03E-6

Table 1. DC Motor estimated parameters.

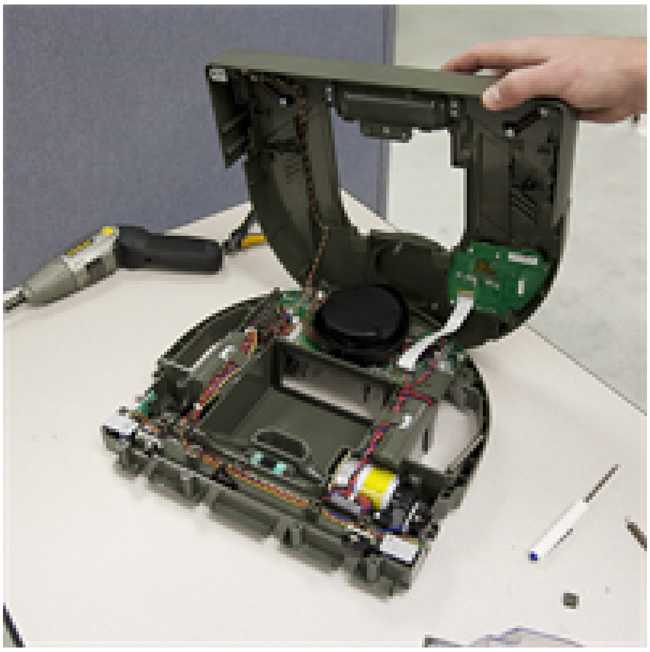

Fig. 6. Neato XV-11 (10)

3. HACKED NEATO XV-11 LASER SCANNER

In mobile robotics applications the most common tasks comprise mapping, localization, navigation and obstacle avoidance. In order to perform them efficiently, the robot needs to sense, calculate the distances to the obstacles and to build the map for robot navigation.

To achieve that, laser scanners are widely used in mobile robotics localization systems (7)(8) but, despite the enormous potential of its use, their high price tag is a major drawback, mainly for hobbyist and educational robotics practitioners that usually have a reduced budget. The Neato XV-11, shown in Figure 6, is a robot sold to vacuum domestic rooms(9), that includes a low cost 360 degree laser distance scanner. The laser scanner can be removed from the XV-11, allowing robotics practitioners to use it in their projects, being a very low cost alternative (10).

A comparison between three laser rangefinders (URG-04LX, XV-11 laser scanner, Kinect derived) was developed (11), the XV-11 laser demonstrated to be reasonable accurate and precise with the more competitive cost. In (14) Neato XV-11 was used for Simultaneous Localization and Mapping, being modeled and simulated using V-Rep software with satisfactory results.

As described by *Konolige et al.* in (11), the Neato XV-11 laser scanner, shown in Figure 8, is a low-cost laser scanner equipped with features like eye-safe, fully functional in standard indoor lighting conditions and some outdoor conditions, it is small sized and has a low power consumption. Instead of using time of flight measurement, like the more expensive laser scanners, it uses triangulation to determine the distance to the target, using a fixed-angle laser, a CMOS imager and a DSP for subpixel interpolation (12).

The sensor establishes a serial communication with a 115200 bps baudrate, sending data with a 5 Hz acquisi-

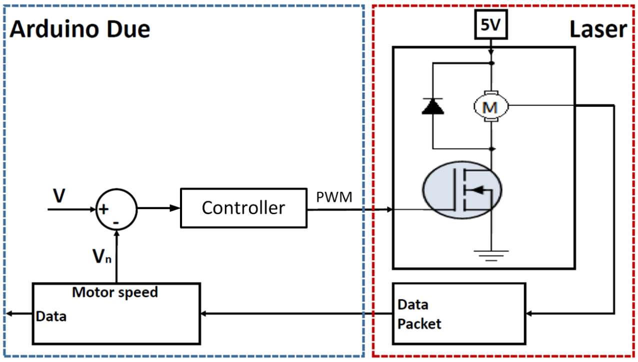

Fig. 7. Laser scanner motor closed loop control.

Fig. 8. Hacked Neato XV-11 laser scanner.

tion frequency. Its power consumption without motor is relatively low: 145 mA @ 3.3 V, which is a very important factor in order to increase the autonomy of a mobile robot with its power based only on the on-board batteries.

It provides a 360° range of measurements, with an angular resolution of 1°, with its range from 0.2 m up to 6 m with an error inferior to 0.03 m. When the laser scanner is removed from the Neato XV-11 robot, its motor has to be controlled by the user, being necessary to be powered with 3.0 V continuous voltage (60 mA), in order to produce a turn rate of 240 rpm. Typically it is used a voltage regulator to obtain the 3.0 V. Although this approach is the most popular, it is not the most efficient, because it is an open loop control, being observed oscillations in the motor velocity. An alternative to the referred approach is the use of the turn rate information contained in the data to close the loop (9) (11).

In this project the motor was controlled in closed loop. To control and to obtain measurements of the hacked Neato laser scanner, it was used an Arduino Due, which provides the 3.3 V requested by the laser scanner and can establish the needed serial communication. The data packet sent by the sensor is composed by a start header, an index byte, the motor speed (V_n), the laser measured data and a checksum.

Using the received motor speed data the control loop is closed by calculating the error relative to the speed (V), needed to maintain the laser frequency up to 5 Hz (5 Hz @ 240 rpm). Posteriorly the error is passed by an integrative like filter, resulting in a PWM control signal, which actuates on a N-Channel Mosfet powering the motor. In Figure 7 it is shown the control loop diagram.

To model the hacked Neato XV-11 Laser Scanner an experimental setup was developed in order to obtain several measurement datasets. The data was obtained with the goal of extracting information about the sensor minimum and maximum ranges, its measurement error and noise. Details of the experimental setups used in order to obtain the laser scanner model and its simulation can be found in (13).

In Figure 9 are shown the mean values of the samples of each dataset relative to the real distance. As it can be seen in Figure 10 the laser scanner measurements tend to increase the error with the distance, reaching values up to 0.54 m at 5 m measurements to the object.

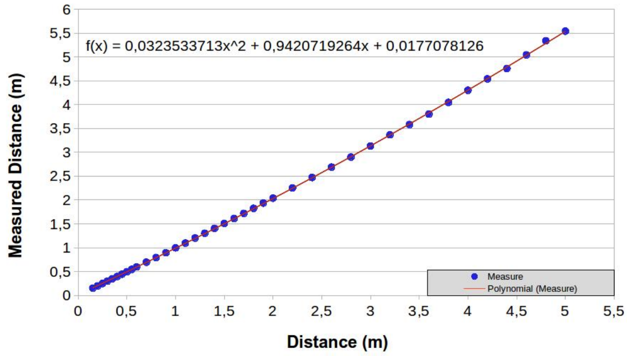

Fig. 9. Distance measured by the laser scanner.

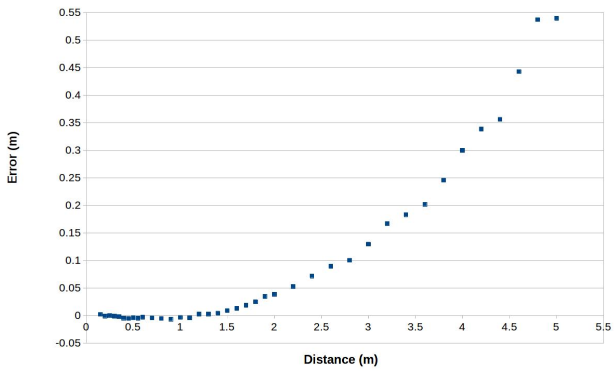

Fig. 10. Distance error

An example of the laser scanner measure histogram is shown in Figure 11. In order to demonstrate that sensor provides data with a gaussian probability distribution it was used the normal probability plot, which is a graphical technique for assessing whether or not a data set is approximately normally distributed. The data is plotted against a theoretical normal distribution in such a way that the points should form an approximate straight line. Departures from this straight line indicate departures from normality (15). The points in Figure 12 form a nearly linear pattern, which indicates that the normal distribution is a good model for this data set. The effect of the discretization on the measurement is also observable.

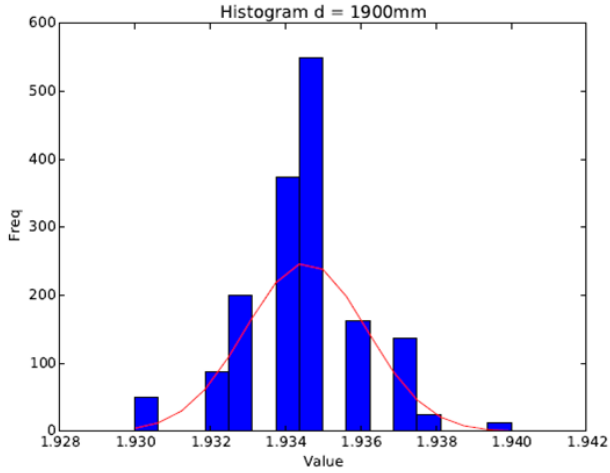

Fig. 11. Laser scanner measure probability distribution.

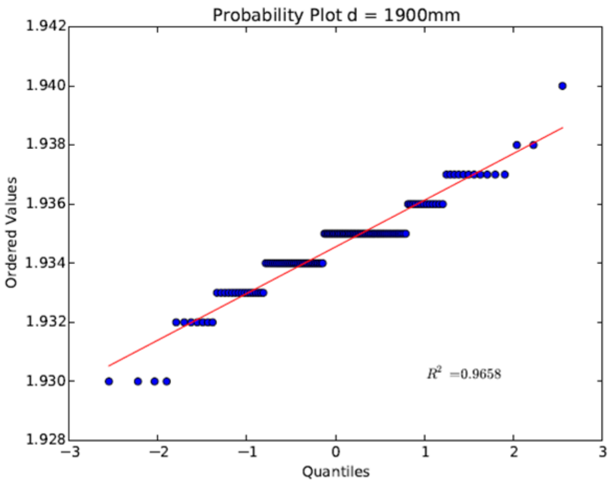

Fig. 12. Normal probability plot.

4. MACHINE AND MATERIAL PART STATUS IDENTIFICATION

Each machine provides an area where the pieces should be placed in order to be processed by the machine. The robot must pick and place the material parts from the machine. While the part is placed in the machine it is processed and should not be removed. An RGB LED indicates that the machine is able to accept parts (light green), the machine is processing a part (yellow light), the part in this machine is already processed (white light) or that the machine is broken (blink red light). The material parts must also be identified by the robot, different colors mean different operations that have to be carried out by the robot. An example of a material part is shown in Figure 13.

In order to identify the material parts and the machine status image processing was used, being the robot equipped with a PS3 Eye camera, as shown in Figure 14.

Examples of the spectral analysis across a band of three images are shown in Figures 15, 16 and 17 (19).

Fig. 13. Material part

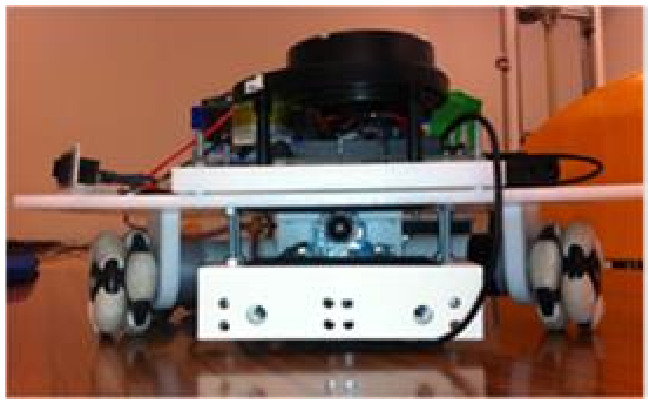

Fig. 14. Prototype front View.

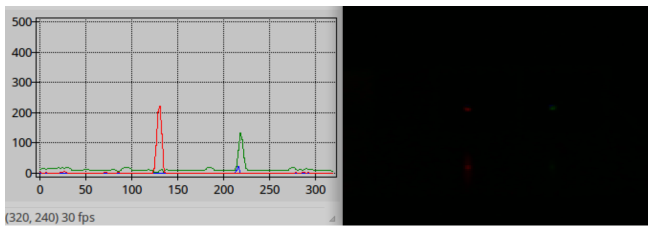

Fig. 15. Spectral analysis example 1.

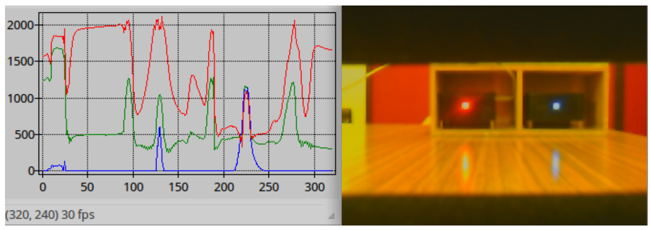

Fig. 16. Spectral analysis example 2.

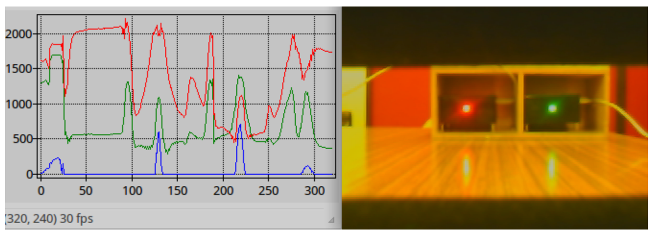

Fig. 17. Spectral analysis example 3.

5. CONCLUSIONS AND FUTURE WORK

In this paper it was presented the proposal of a Low cost Mobile Robot prototype with On-Board Laser Scanner, prototyped to compete at the Robot@Factory Mobile Robot competition. It is also presented the description of its sensors and actuators, providing valuable information that can be used to develop better designs of controllers and localization systems. The robot is equipped with the 37Dx52L, which is a low cost 12v motor equipped with encoders and a 29:1 reduction gearbox, being a very popular actuator in the mobile robotics domain. The robot is also equipped with a hacked Neato XV-11 Laser Scanner, being a very low cost alternative, when compared with the current available laser scanners.

One educational aspect, other than the natural motivating factor, is the availability of a challenge that is harder than some entry level competitions but still reachable for teams with some experience on those tasks. Also, it is expected that the problem scales well to more complex approaches. This means that more complex robot, thus a harder robot to build, will also be able to perform better. This can be a excellent motivation for teams to learn and use more advanced robots and algorithms.

By presenting a scaled down factory shop, this competition creates a benchmark that can be used to compare different approaches to the problems that arise on this kind of environments. Also, the ability, in some restricted areas, to alter the environment, can promote the test and evaluation of different localization mechanisms. Something that is usually, more restricted in most other competitions. That opens this area to be explored and benchmarked.

As future work the authors intend to develop localization and navigation systems for the proposed robot, in order to participate in the Robot@Factory competition in a competitive way.

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